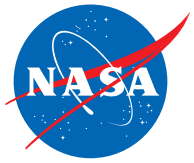


Jet Propulsion Laboratory
California Institute of Technology

Assessment of surface mass balance uncertainties using a surface energy balance model and the Ice Sheet System Model framework

12/14/2018

Nicole-Jeanne Schlegel [1]

Eric Larour [1], Alex Gardner [1], Ala Khazendar [1], Tristan L'Ecuyer[2], Michiel van den Broeke[3]

[1] Jet Propulsion Laboratory, California Institute of Technology
[2] University of Wisconsin-Madison, Madison, WI
[3] Institute for Marine and Atmospheric research Utrecht (IMAU), Utrecht University, The Netherlands

ISSM (Ice Sheet System Model) and the GEMB (Glacier Energy and Mass Balance) module

The GEMB module is now integrated into ISSM, so it can be launched using the ISSM parallelized framework.

GEMB:

- designed Alex Gardner during his thesis work (Gardner and Sharp, 2010)
- 1-D column model
- simulates the radiation balance and evolution of the snow pack i.e. temporally evolving firn density profiles
- forced by 3-hourly precipitation, solar irradiance, downwelling longwave radiation, near-surface wind speed, air temperature, and humidity

GEMB Module Simulated Processes

In addition, GEMB includes a detailed representation of surface and subsurface processes

- Surface albedo (four methods implemented)
  (Gardner and Sharp 2010, Brun et al. 2009, Greuell & Konzelmann 1994, Bougamont & Bamber 2005)
- Sensible and latent heat fluxes
- Longwave emittance
- Melt-water generation
- Percolation and refreeze
- Pore water retention
- Snow compaction (four models implemented)
  (Herron and Langway 1980, Arthern et al. 2006/2010, Li and Zwally 2004, and Ligtenberg et al., 2011/Kuipers Munneke et al. 2015 [after IMAU-FDM])
- Snow grain growth
- Thermal diffusion
- Subsurface absorption of shortwave radiation

Main Science Goal:

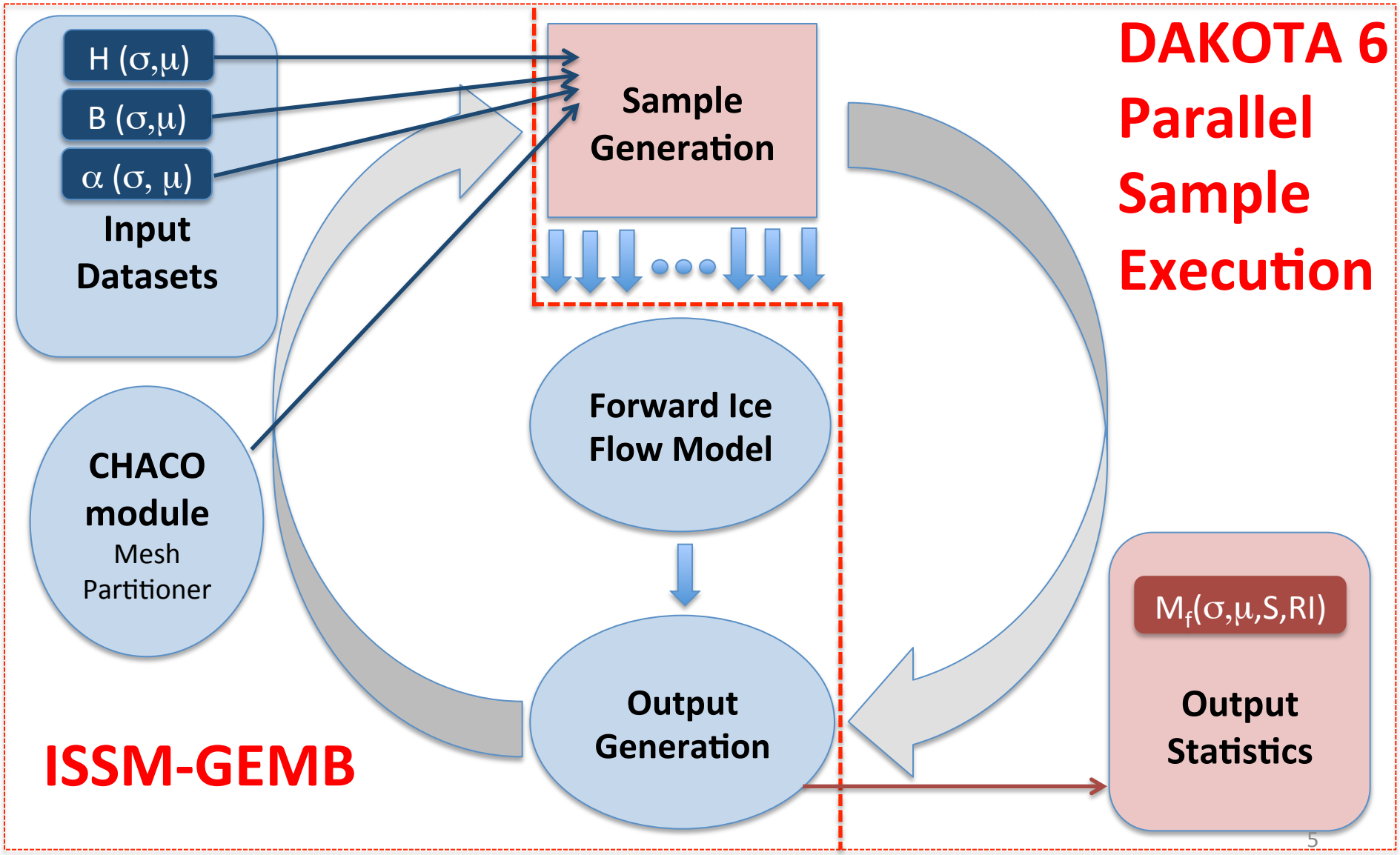
To better constrain uncertainty of local changes in ice mass when converting from altimetry-derived surface elevation changes (e.g. in ISSM assimilation of altimetry signals)

Current Strategy:

To conduct sensitivity and uncertainty quantification studies using ISSM-GEMB framework

- propagate errors from various climatological estimates of surface input into the top layers of the GEMB simulation, to better quantify uncertainties in the temporal evolution of key output (e.g. FAC).

Design Analysis Kit for Optimization and Terascale Applications (DAKOTA) software, embedded in ISSM



Our goal is to utilize efficiency of ISSM and Uncertainty Quantification (UQ) tools to better understand GEMB sensitivity

Examples:

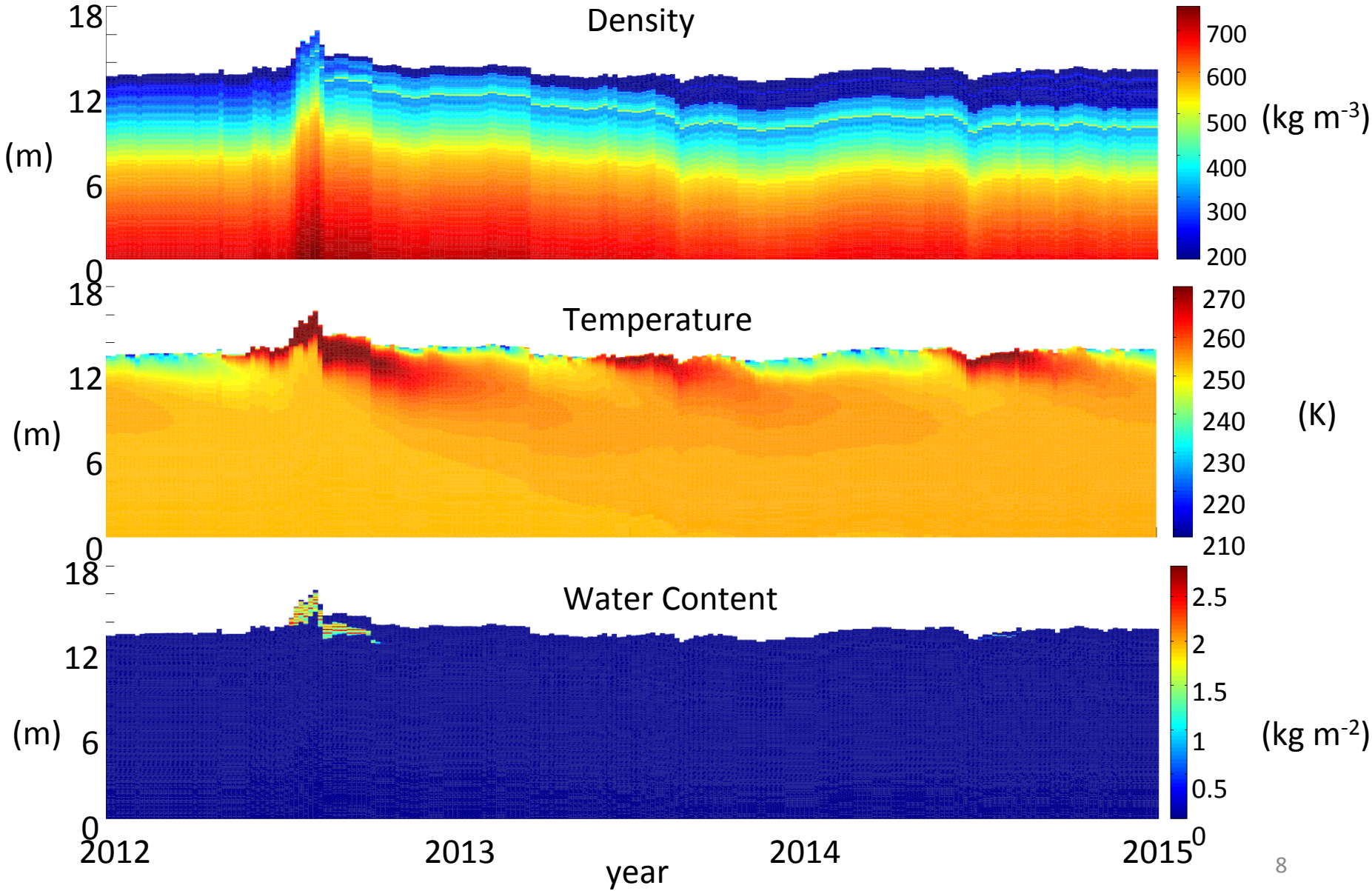
- Run forced with different regional climate model input (RACMO, MAR)
- Test result sensitivity to temporal and vertical resolutions
- Run with different densification and albedo schemes
  - Model updated to ingest observations in albedo (i.e. MODIS), now possible to run sampling techniques on albedo input
- Perturb standardized climatology with anomalies generated from reanalysis (i.e. MERRA-2, CSR, NCEP-R2, ERA-Interim, ERA5)
  - intra- and inter-annual variations in temperature, net radiative balance, and precipitation

Example Evaluation:

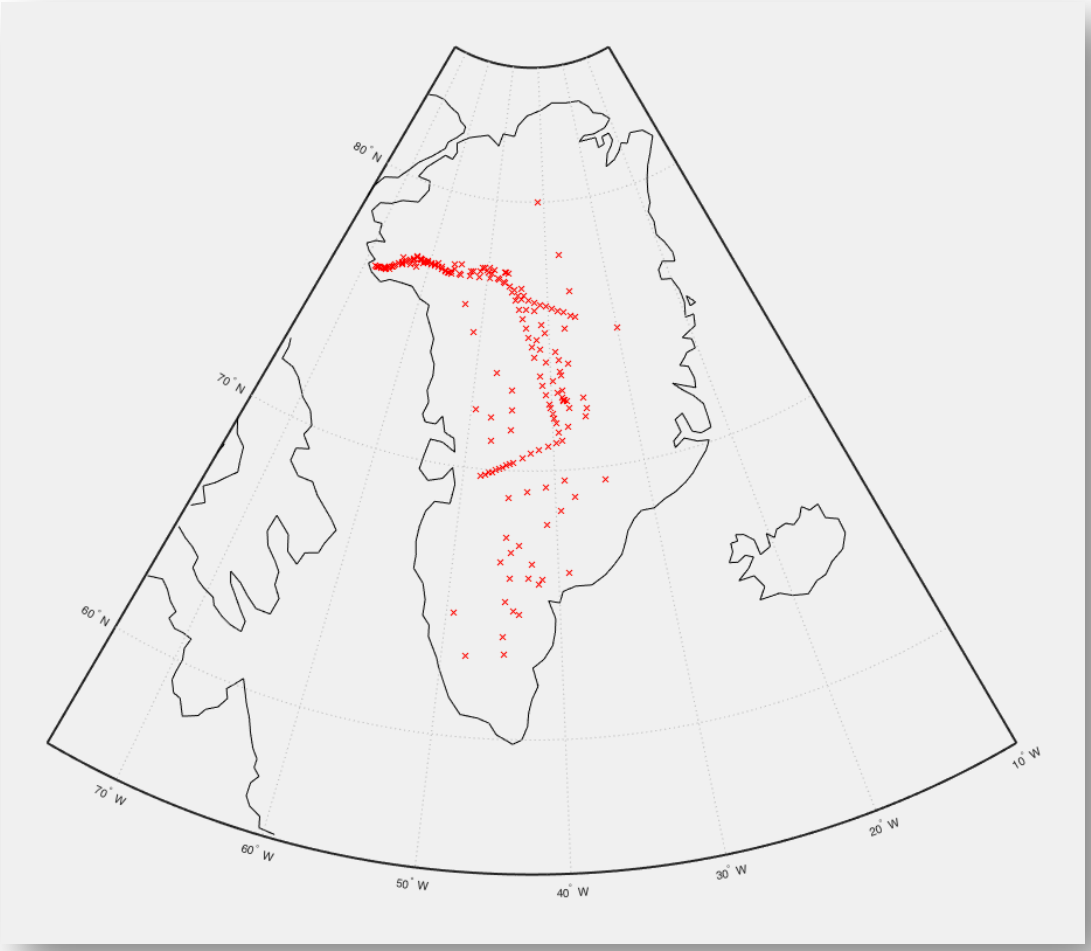
Simulation of Greenland firn properties with RACMO

GEMB models temporal evolution of firn properties

Example: Greenland, Camp Century (2012-2014) forced with 3 hourly RACMO2.3



To evaluate and improve model firn densification, we use the SUMup database to tune the densification parameterization



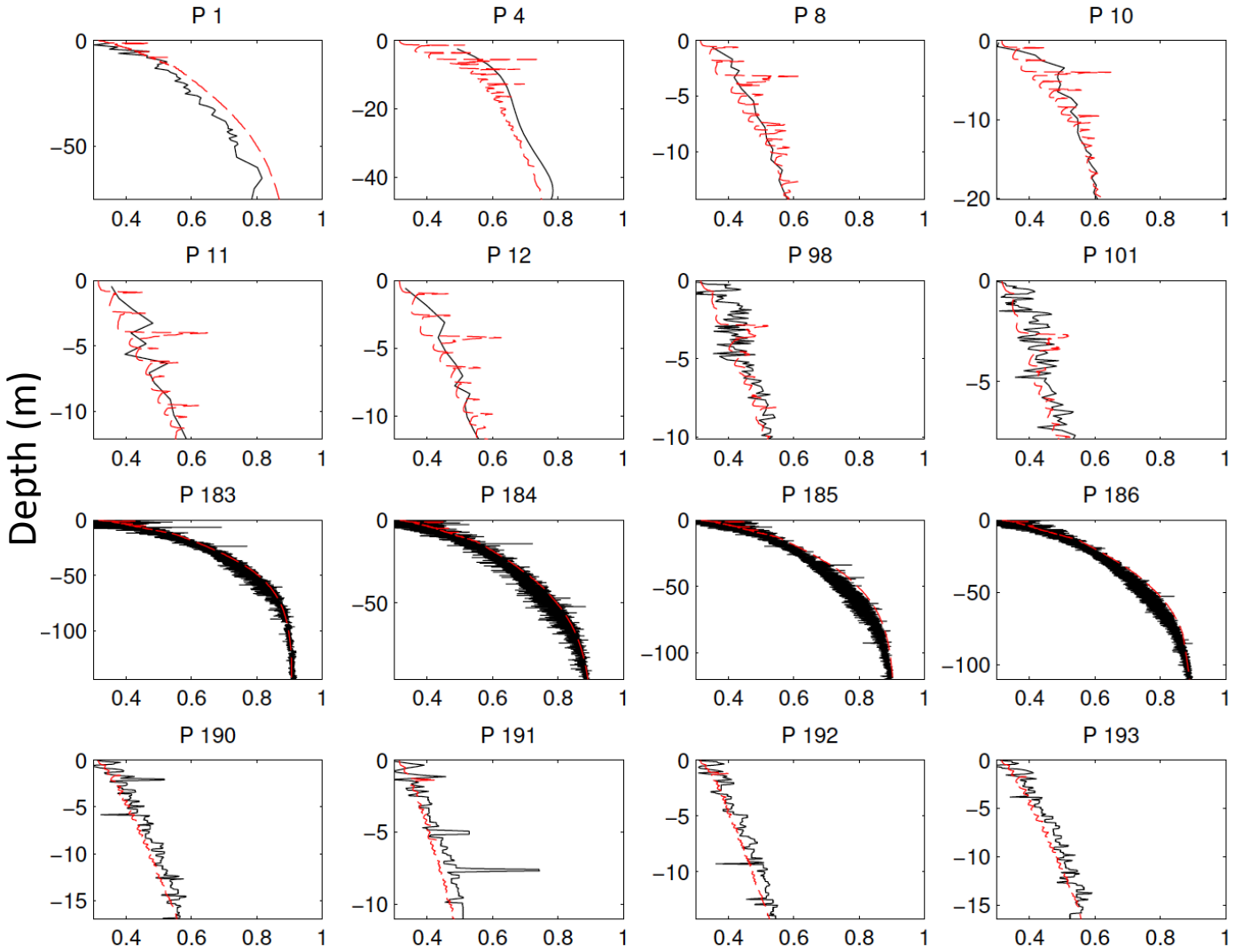
196 SUMup Total Cores

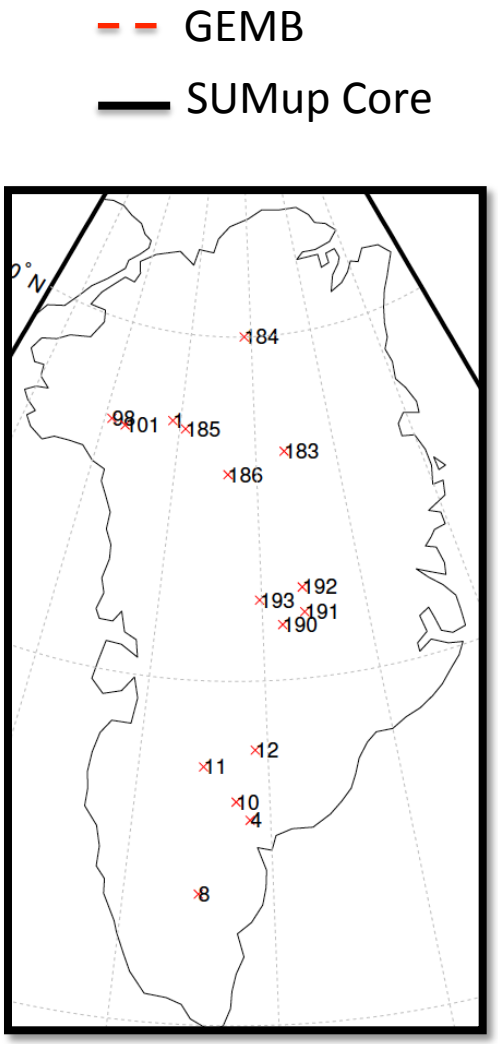
Arthern et al. (2010) Parameterization tuned after Kuipers Munneke et al. (2015)

30 *cores for 550 kg m^{-3} level*
7 *cores for 830 kg m^{-3} level*

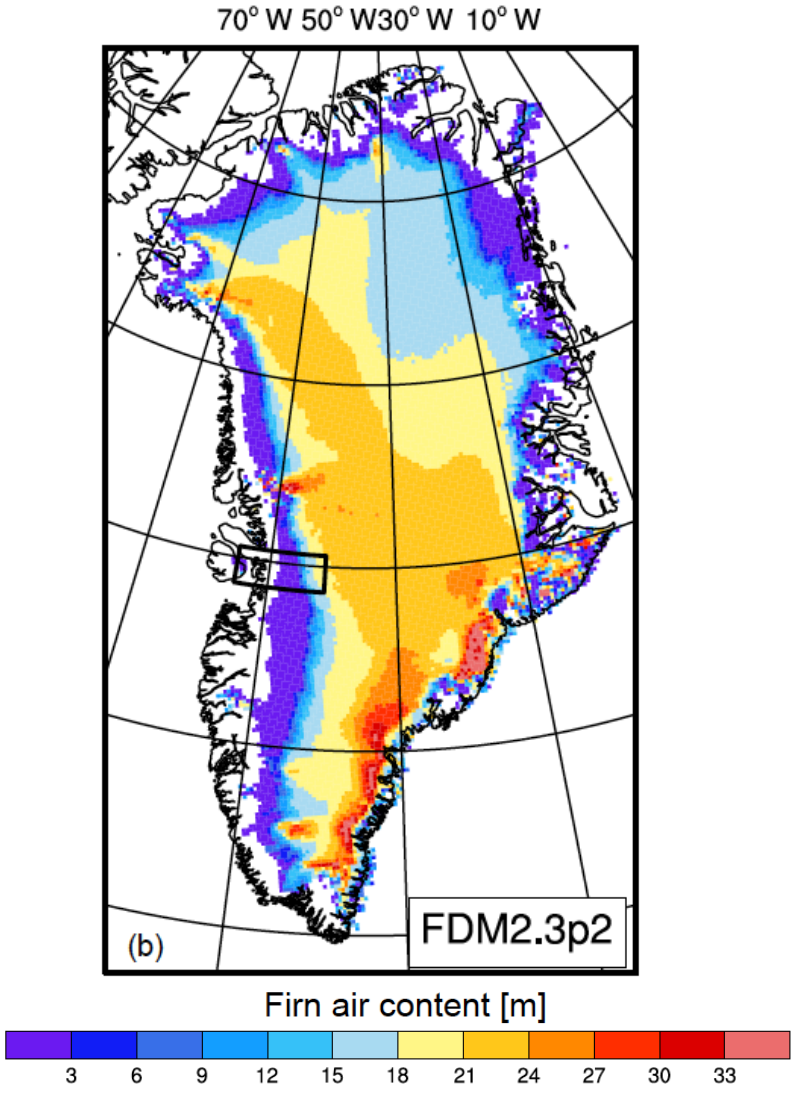
[Lora Koenig and Lynn Montgomery. Surface Mass Balance and Snow Depth on Sea Ice Working Group (SUMup) snow density subdataset. urn:node:ARCTIC. doi:10.18739/A2BJ96]

Preliminary comparison between core densities and modeled densities around reveals a promising start for evaluation of densification model

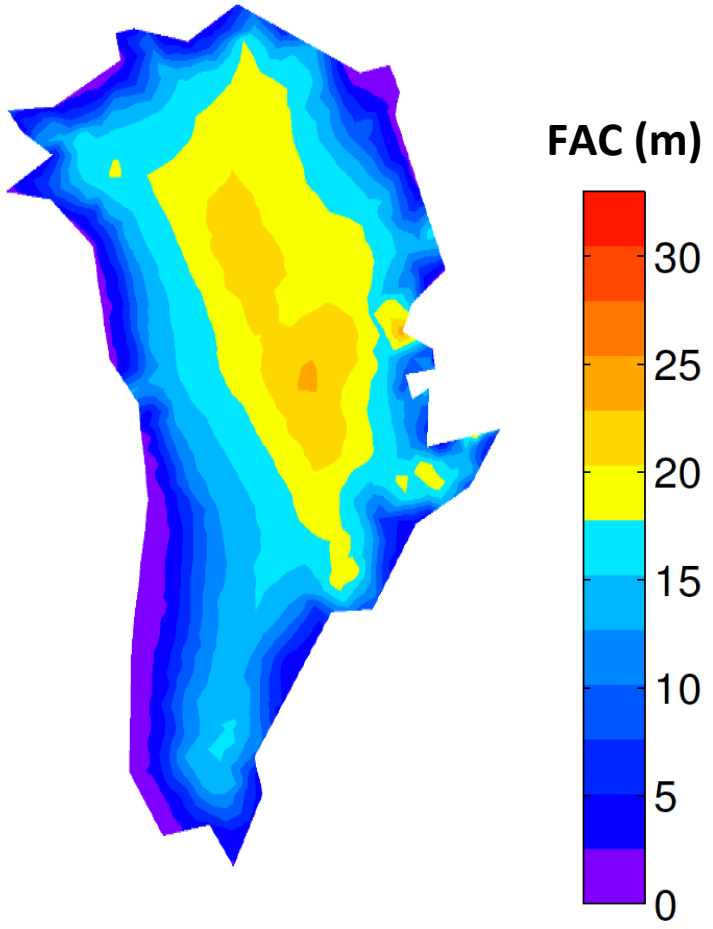




ISSM-GEMB simulation (1979-2015) of Greenland radiation balance produced firm air content below that of IMAU-FDM estimates

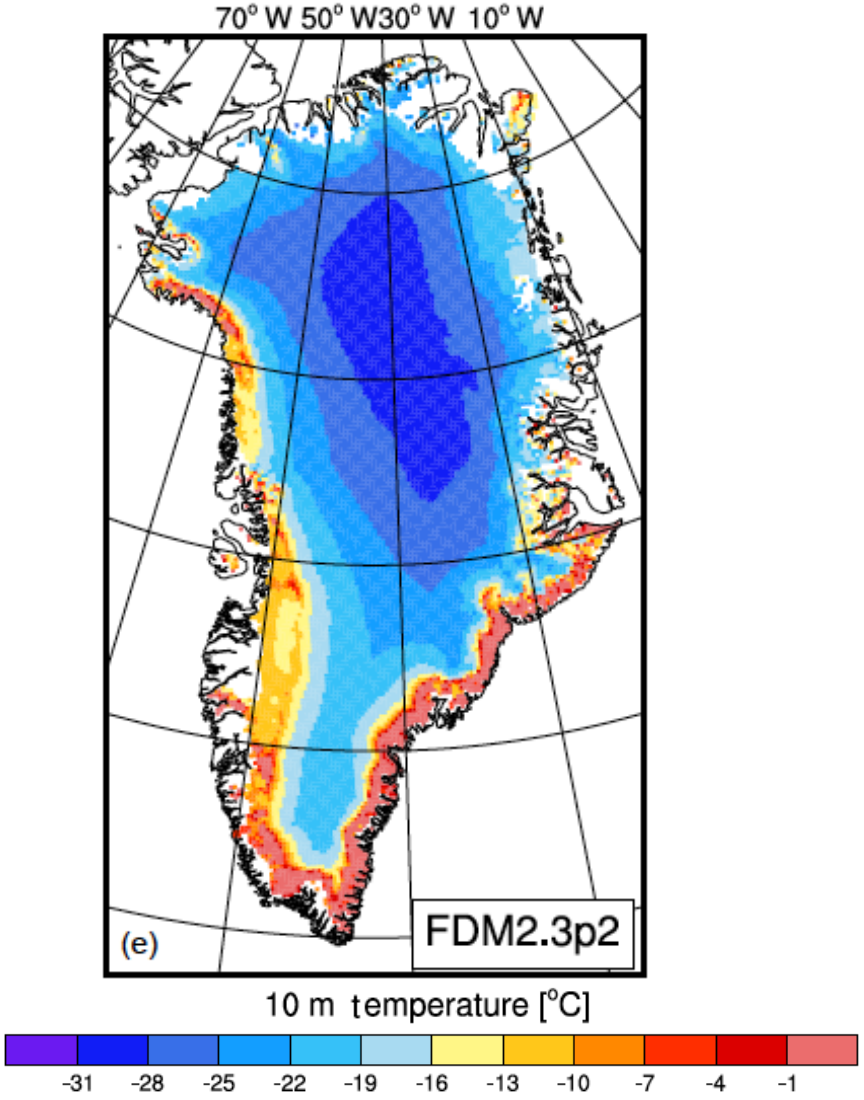


[Ligtenberg, Cryosphere (2018)]

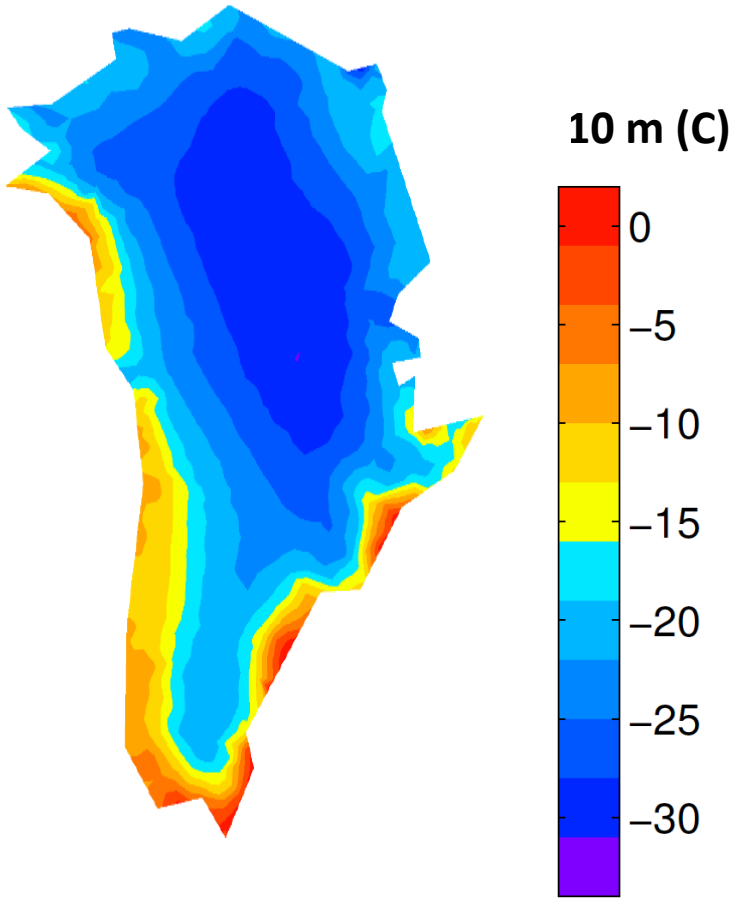


GEMB FAC
Mesh 50 km resolution
5000 year relaxation

The resulting 10 m temperature from ISSM-GEMB simulation compares well with IMAU-FDM estimates



[Ligtenberg, Cryosphere (2018)]

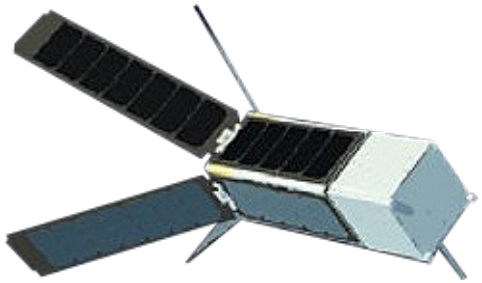


GEMB 10 m Temperature
Mesh 50 km resolution
5000 year relaxation

Example:

Sensitivity of SMB to outgoing longwave radiation:
A preliminary science study for the Polar Radiant Energy in the Far Infrared Experiment (EVI-4) (PREFIRE)

PREFIRE will measure far-infrared emissions over Greenland

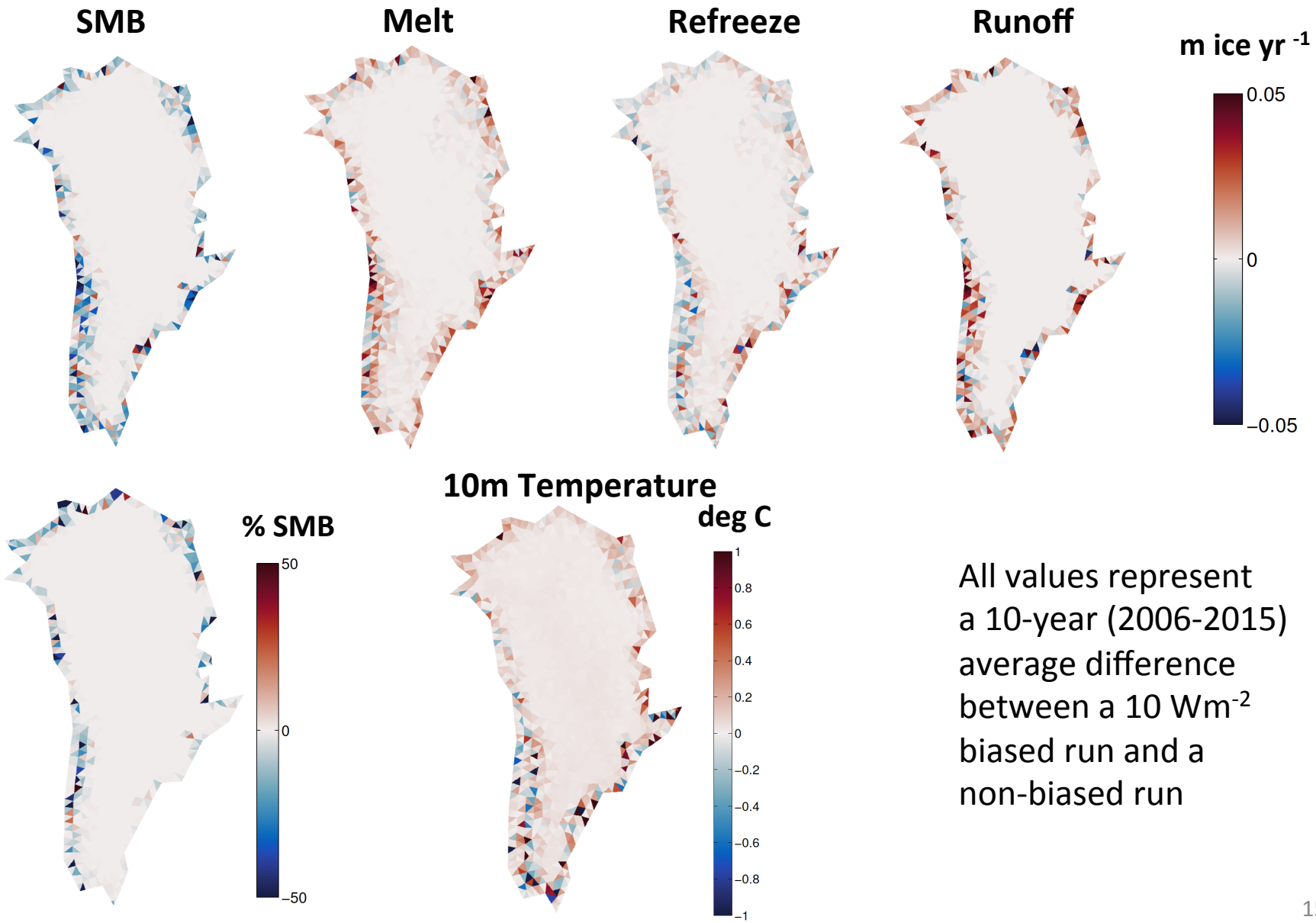


⇒ The two PREFIRE CubeSats will orbit the poles to measure far-infrared emissions at a sub-daily resolution.

⇒ These measurements will aid in assessment of how thermal infrared emissions at the top of Earth's atmosphere are related to ice sheet surface conditions (e.g. presence of melt water).

Preliminary experiments suggest that current measurements of surface emitted longwave radiation are biased by ~10 Wm^{-2} over Greenland

We use sensitivity studies to estimate the biases in surface mass balance (SMB) And components that results from 10 Wm^{-2} less long wave emissions upward



All values represent a 10-year (2006-2015) average difference between a 10 Wm^{-2} biased run and a non-biased run

Example:

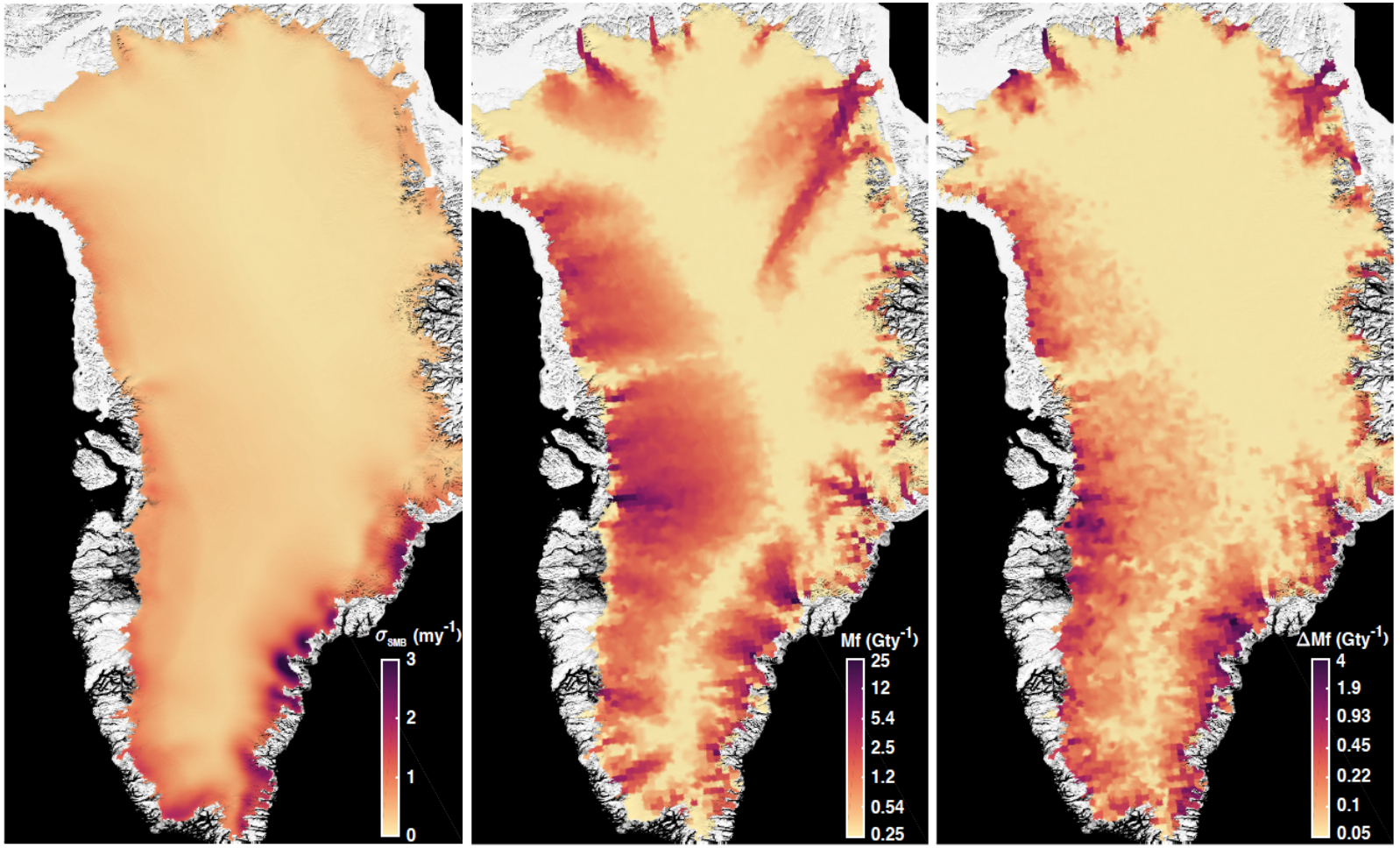
How ISSM UQ can propagate SMB errors as uncertainty in ice flow

ISSM-DAKOTA sampling of a Greenland forward simulation reveals that mass flux is sensitive to errors in SMB on a decadal scale (1960-2012 forward simulation)

Estimated Surface Mass Balance Error

Mean Mass Flux Dec. 2012, 18 km resolution

Dec. 2012 Mass Flux Uncertainty Propagated from SMB error



Future Outlook

- Quantification of uncertainties and model bias will allow us to:
  - better constrain local changes in ice mass when converting from altimetry-derived surface elevation changes
  - characterize which surface forcing is most responsible for variations in surface elevation signals
  - inform missions where measurements of surface radiation budget and surface processes are most important

- ✓ This is a significant assessment for the assimilation of altimetry signals into historical reconstructions using ISSM.
- ✓ In the future, analysis will aid in the reduction of the parameter space of surface forcing that must be weighted during ISSM reconstruction of surface change.
- ✓ This work will inform ISSM/altimetry assimilation with reasonable bounds for surface forcing that have the largest influence over surface elevation change.

Thank you!